Dilution Factor and Systematic Error

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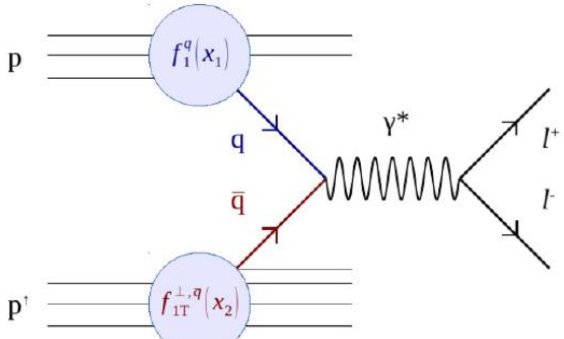
Outline:

- SpinQuest introduction
- Polarized target & dilution factor
- Cross-section generator
- Sources of error
- Dynamic dilution factor error
- Summary

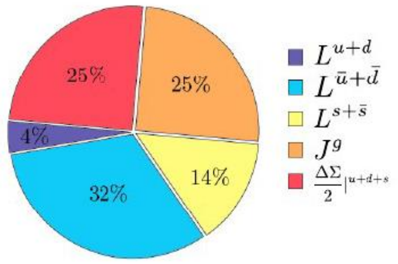
SpinQuest Introduction

- Find the contribution of the constituent partons to the nucleon spin.
- Sivers function describes the correlation between the momentum direction of the struck quark and the spin of its parent nucleon
- If sea-quark Sivers asymmetry is non-zero, then sea quarks have non-zero OAM.
- Measure the Sivers asymmetry for the $\bar{u}$ and $\bar{d}$ sea quarks using the Drell-Yan process.
- In order to measure the Sivers function we need a polarized target.

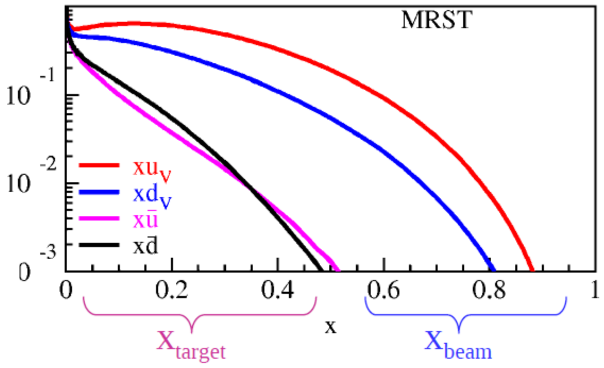


$$A_N^{DY} \propto \frac{\sum_q e_q^2 \left[f_1^q(x_1) \cdot f_{1T}^{\perp,\bar{q}}(x_2) + 1 \leftrightarrow 2 \right]}{\sum_q e_q^2 \left[f_1^q(x_1) \cdot f_1^{\bar{q}}(x_2) + 1 \leftrightarrow 2 \right]}$$

Drell-Yan process and the Sivers Assymetry equation



Proton spin components
Lattice QCD: K.-F. Liu et al arXiv:1203.6388



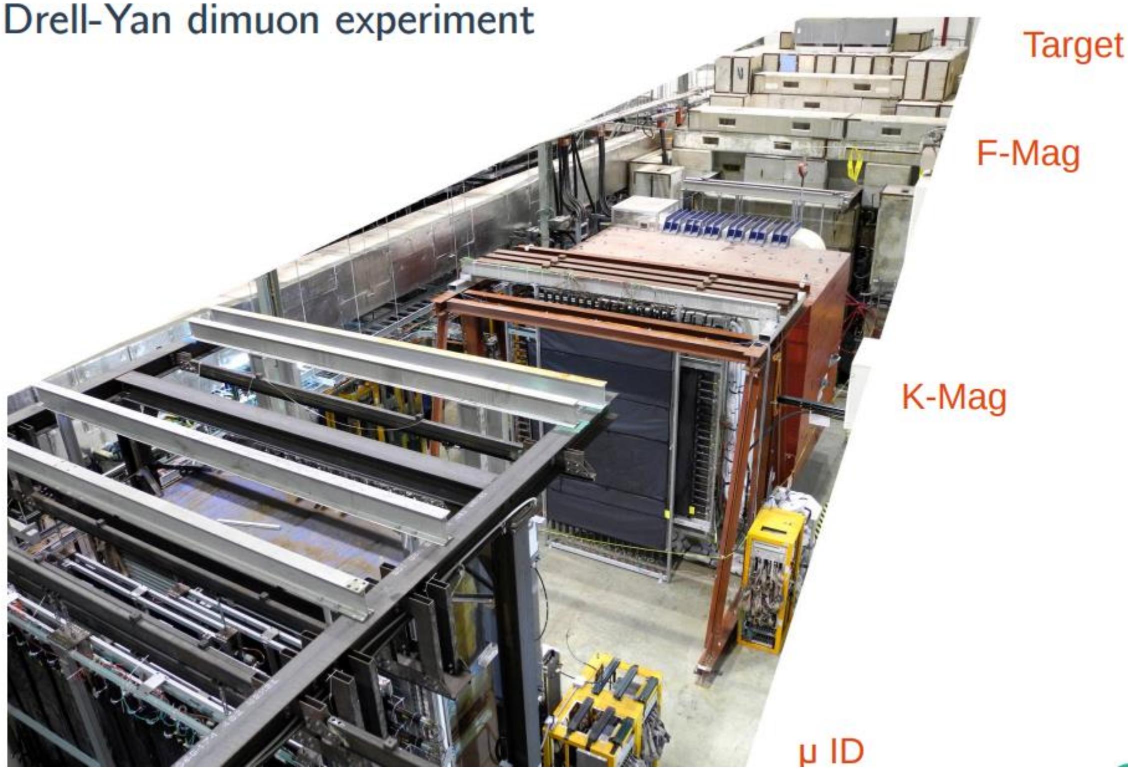
Kinematics dependence MRST x target Xbeam

$$A_T = \frac{2}{f|S_T|} \frac{\int d\phi_S d\phi \frac{dN(x_B, x_T, \phi, \phi_S)}{d\phi_S d\phi} sin(\phi_S)|}{N(x_b, x_T)}$$

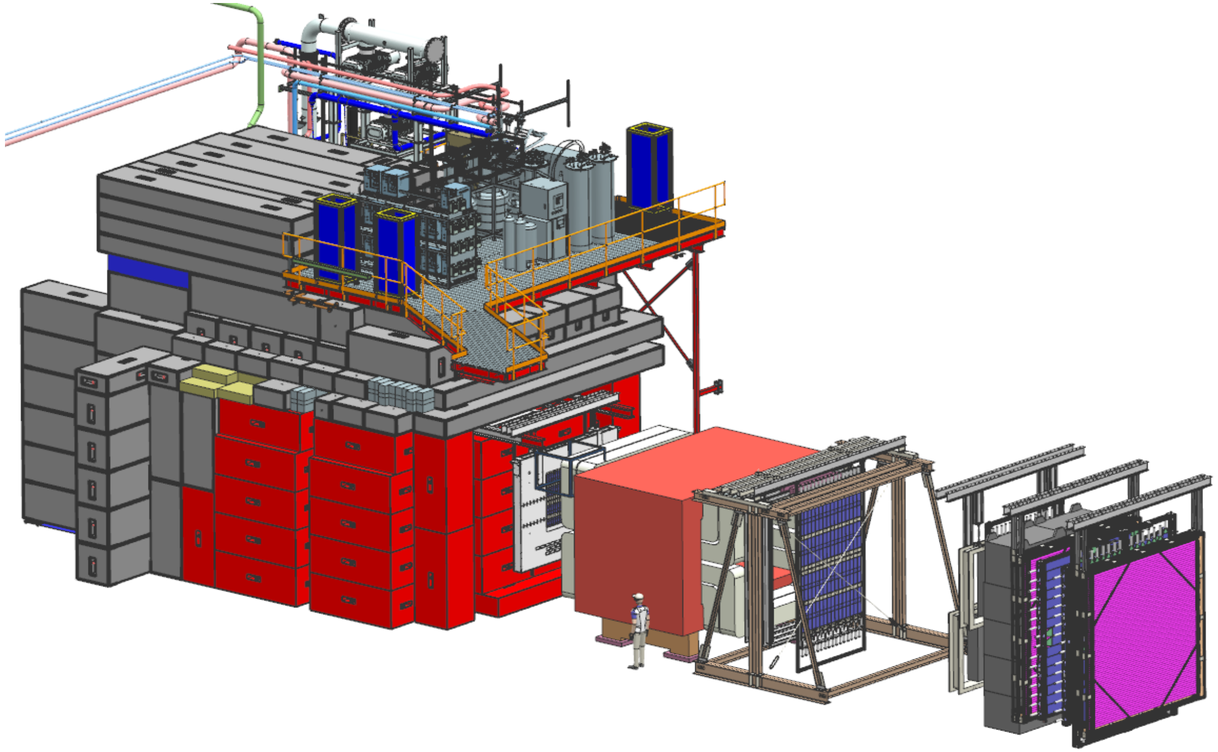
$$\frac{d^2\sigma}{dx_b dx_t} = \frac{4\pi\alpha^2}{x_b x_t s} \sum_{q \in \{u,d,s,\dots\}} e_q^2 \left[\bar{q}_t(x_t) q_b(x_b) + \bar{q}_b(x_b) q_t(x_t) \right]$$

E-1039 Experimental Setup

A Drell-Yan dimuon experiment



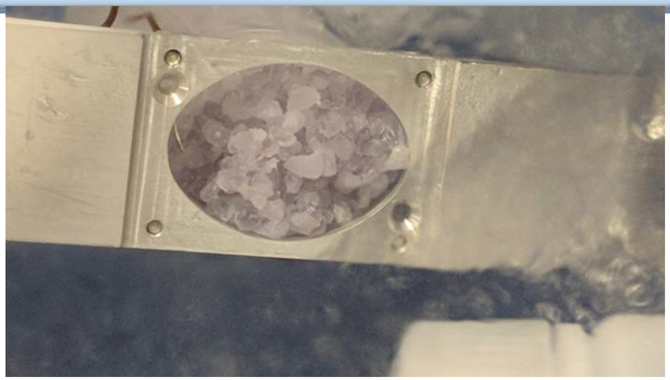
Detector system assembly



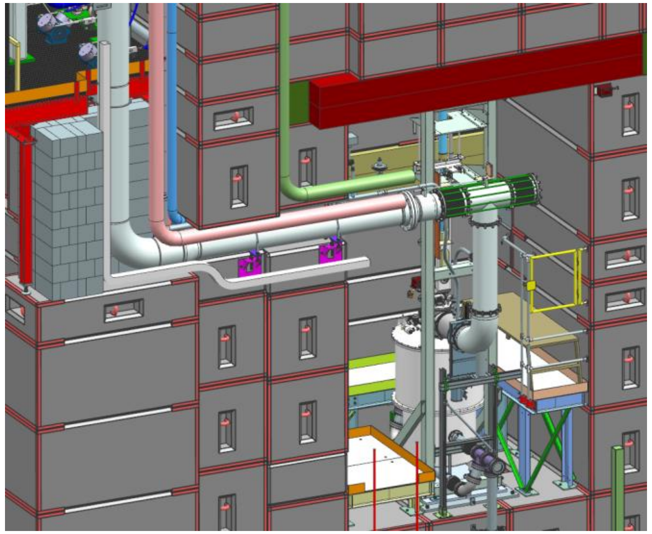
- 120 GeV proton beam from the main injector
- 4s Beam spill every 60s
- 19 ns RF ~10s K proton per RF bucket
- ~4x10^{12} proton on target(POT) per spill
- Project proposed to run for 2 years

Target

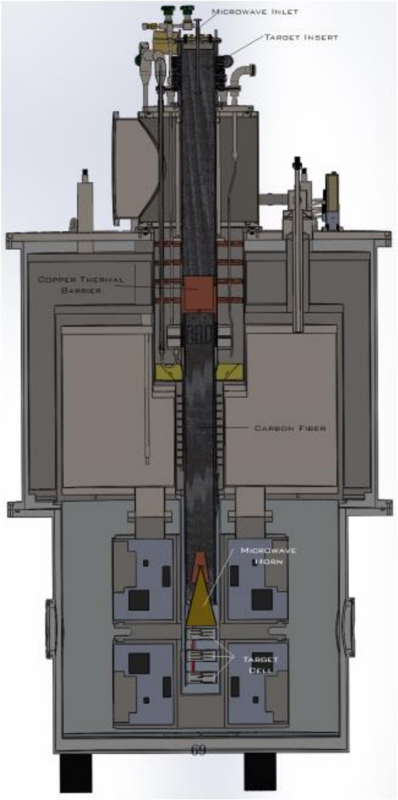
- The target consists of an 8cm long PTFE target cells containing ammonia beads immersed in liquid Helium.
- The cooling power of the He-evaporation refrigerator is 1.4 W at 1 K assuming a flow rate of 20 SLPM (normal operation).
- Our target system will contain polarized NH_3 (proton target) and polarized ND_3 (neutron target)
- $dB/B < 10^{-4}$ at 5T over 8 cm
- This is the highest cooling power DNP (Dynamic Nuclear Polarization) target in the world due to the high pumping rate and the refrigerator. Pumping rate >14000 m^3/hr.



Target cup filled with material



Target in the alcove



Target with the insert

NH_3 & ND_3 Targets

Running time for a chosen accuracy $\propto \dfrac{1}{P_T^{2} \cdot \rho . f^2 \, \kappa}$

κ= packing fraction

ρ = density

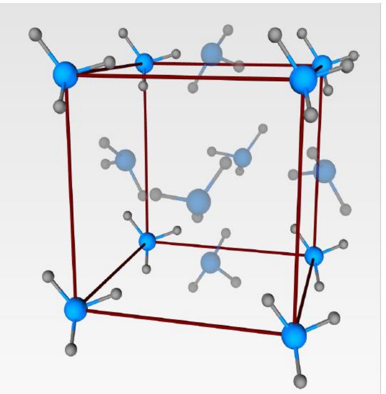
f= dilution factor

$^{14}NH_3$

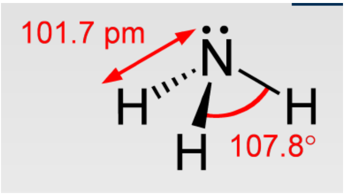
- Optimized proton target
- Moderate f
- High resistance to radiation damage
- Polarization calibration error ~3%

$^{14}ND_3$

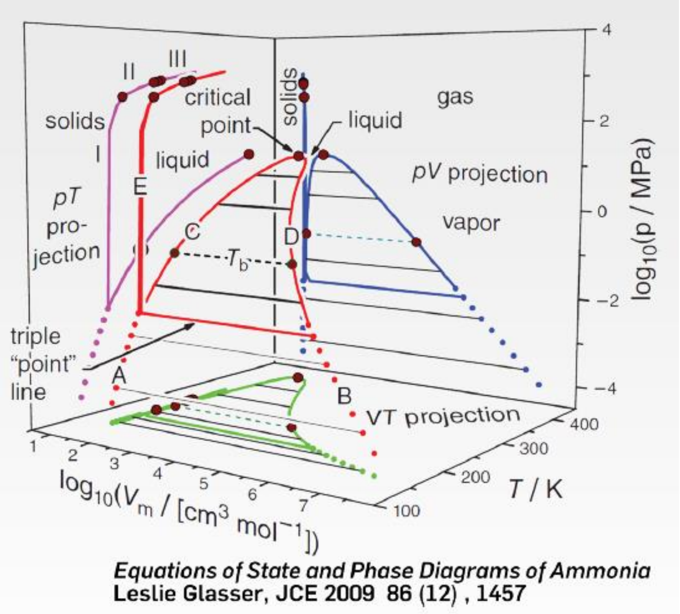
- Optimized neutron target (P_n=0.91P_D)
- Larger f
- High resistance to radiation damage
- Polarization calibration error ~5%



Cubic structure of Ammonia



Ammonia Molecular structure



Spin-1 ^{14}N background, but computable

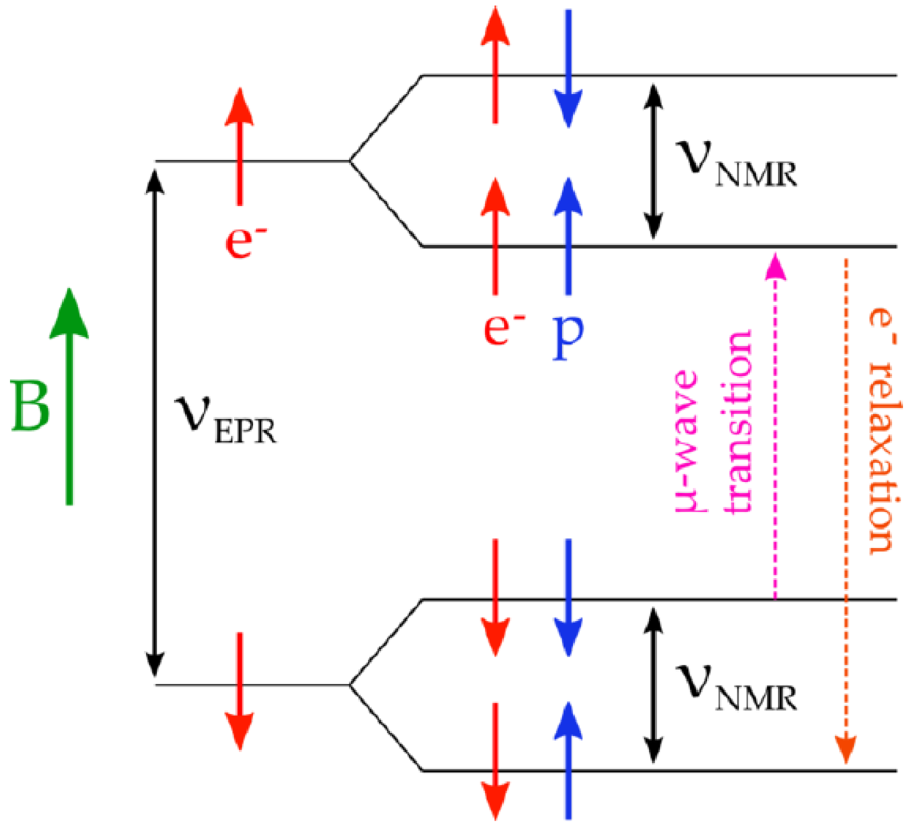
	P_T	ρ	f	κ	FOM
ND_3	0.45	1.007	0.3	0.6	0.0110
NH_3	0.90	0.853	0.176	0.6	0.0128

SeaQuest with a Transversely Polarized Target (E1039)

Dynamic Nuclear Polarization

- Target polarization process
- Transfer of spin polarization from electrons to nuclei
- Electrons 1K 5T ~ 98%
  Protons 1K 5T ~0.5%
- Dope target material with paramagnetic centers
- Using microwave to transfer the polarization to nuclei.
- Microwave frequency: 140 GHz
- Thermal Equilibrium polarization:

$$P = \frac{e^{\frac{\mu B}{kT}} - e^{\frac{-\mu B}{kT}}}{e^{\frac{\mu B}{kT}} + e^{\frac{-\mu B}{kT}}} = \tanh\left(\frac{\mu B}{kT}\right)$$



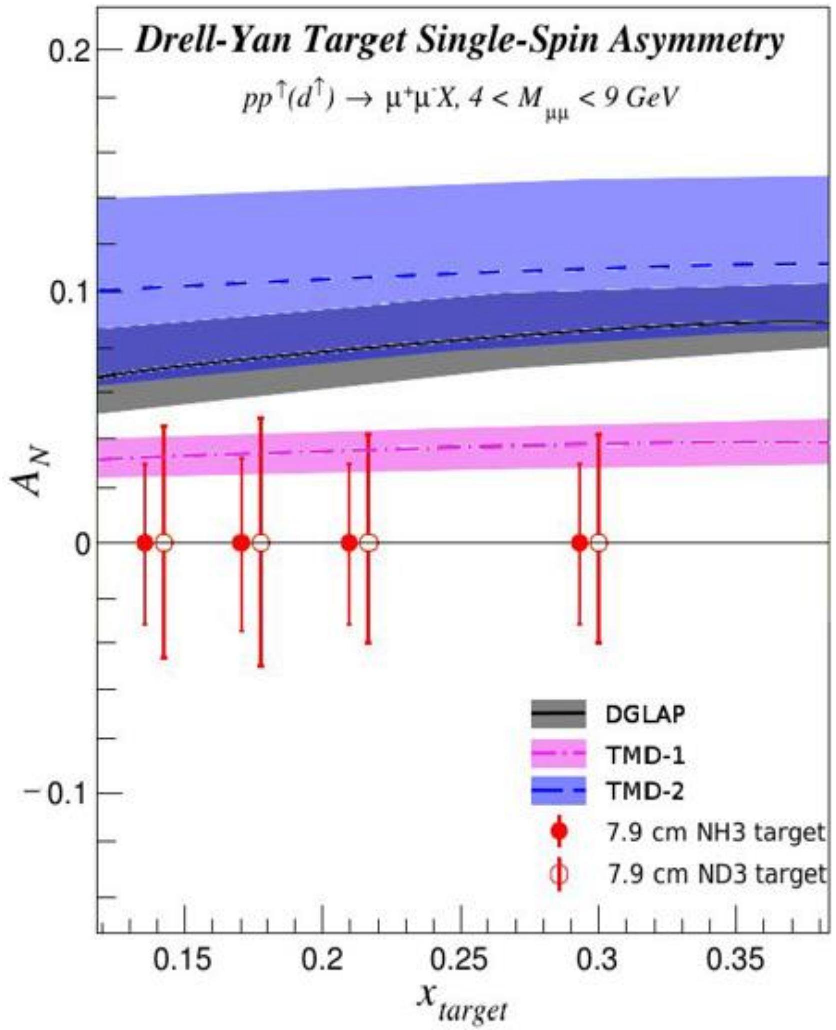
Projections of Error

Beam(~2.5%):
- Relative Luminosity(~1%)
- Drifts(<2%)
- Scraping(~1%)

Analysis sources(~3.5%):
- Tracking Efficiency(~1.5%)
- Trigger and Geometrical Acceptance(<2%)
- Mixed background(~3%)
- Shape of DY(~1%)

Target(~6-7%)

- **Dilution factor(~3%)**
- Polarization inhomogeneity(~2%)
- Packing fraction(~2%)
- Density of target (ammonia)(~1%)
- TE calibration(P~2.5% D~4.5%)
- Uneven radiation damage(~3%)
- Beam/target misalignment(~0.5%)



Dilution Factor

- Static dilution factor is defined as the ratio of number of polarizable nucleons to total no. of nucleons in the target. ***Defines the figure of merit of the target material.***
- Dynamic dilution factor is defined as the ratio of cross section of polarizable nucleons to the cross section of all the nucleons in the target. ***Defines the figure of merit of the experiment.***
- The denominator of the dilution factor can be written in terms of the relative volume ratio of ND_3 to LHe in the target cell, the packing fraction pf .
- For the case of a cylindrical target cell oriented along the magnetic field, the packing fraction is exactly equivalent to the percentage of the cell length filled with NH_3 or ND_3. The dilution factor for NH_3 is 0.176 and for ND_3 is 0.3.
- The uncertainty in these factors from irreducible background is typically 2-3%.

$$f_{NH3} = \frac{N_H}{N_H + NN_{14}} = \frac{3}{3+14} = \frac{3}{17}$$

Static Dilution Factor(Hydrogen)

$$f(x) = \frac{N_H \sigma_{pp_\uparrow}^{DY}(x)}{N_H \sigma_{pp_\uparrow}^{DY}(x) + N_{N14} \sigma_{pp_\uparrow}^{DY}(x) + N_{He} \sigma_{p\,p_\uparrow}^{DY}(x) + N_{Al} \sigma_{pp_\uparrow}^{DY}(x) + \dots}$$

Dynamic Dilution Factor(Hydrogen)

$$f_{ND3} = \frac{N_D}{N_D + NN_{14}} = \frac{6}{3+17} = \frac{3}{10}$$

Static Dilution Factor(Deuteron)

$$f(x) = \frac{N_D \sigma_{pD_\uparrow}^{DY}(x)}{N_H \sigma_{pD_\uparrow}^{DY}(x) + NN_{14} \sigma_{pp_\uparrow}^{DY}(x) + N_{He} \sigma_{p\,p_\uparrow}^{DY}(x) + N_{Al} \sigma_{pp_\uparrow}^{DY}(x) + \dots}$$

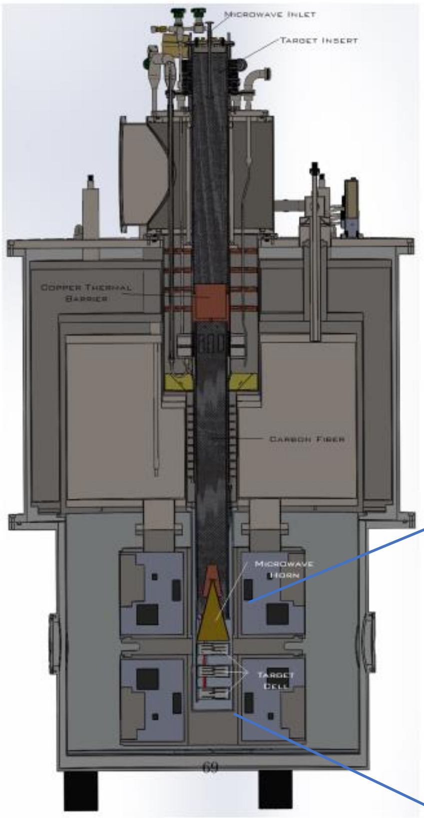
Dynamic Dilution Factor(Deuteron)

Contribution (Non Target)

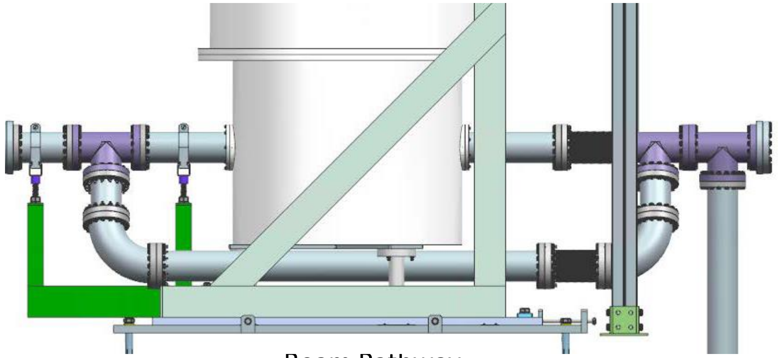
Using the SpinQuest simulation for a particular event rate we find the percentage of dimuon events that are detected, broken down into contributions of materials:

- Aluminum(Nose piece)
- Target cell(PTFE)
- Gold + Copper(microwave horn)
- NMR coils
- Aluminum Foil on the cups
- Aluminum Ladder
- Liquid Helium
- Target material

Notes: ~4x10^{12} protons per spill. What fraction produces dimuon events that we can detect. What fraction are from above listed materials.



Cross-section of the target



Beam Pathway

Target cells with the microwave horn

MCFM (Monte Carlo for FeMtobarn)

- MCFM: parton-level Monte Carlo program, gives NLO predictions for a range of processes at hadron colliders.
- Developed at Fermilab by:

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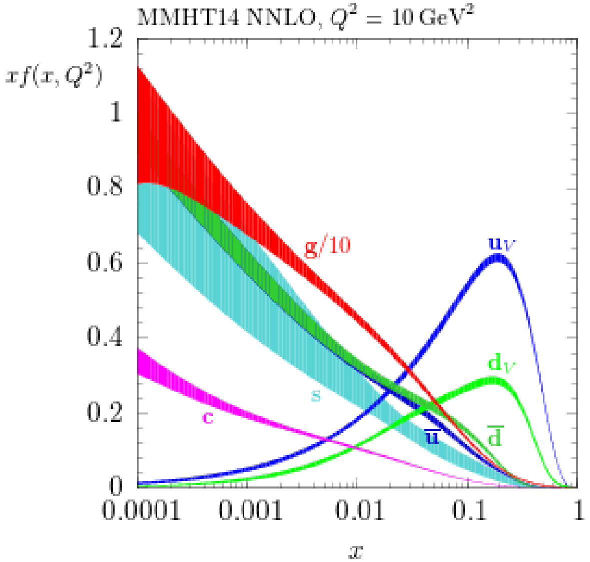
R. Keith Ellis (ellis@fnal.gov)

Walter Giele (giele@fnal.gov)

Tobias Neumann (tneumann@fnal.gov)

Ciaran Williams (ciaranwi@buffalo.edu)

- Best available Drell-Yan cross-section generator(at $\sqrt{s}$ =15GeV)
- Collection of modern parton distribution functions that are included with MCFM.
- Built event generator based on MCFM distributions



pdlabel	$\alpha_S(M_Z)$	order	reference
mstw8lo	0.1394	1	[41]
mstw8nl	0.1202	2	[41]
mstw8nn	0.1171	3	[41]
MMHT_lo	0.135	1	[35]
MMHT_nl	0.120	2	[35]
MMHT_nn	0.118	3	[35]
CT10.00	0.118	2	[38]
CT14.LL	0.130	1	[24]
CT14.NL	0.118	2	[24]
CT14.NN	0.118	3	[24]
CT14qed	0.118	2	[53]
NN2.3NL	0.118	2	[5]
NN2.3NN	0.118	3	[5]
NN3.0LO	0.118	1	[4]
NN3.0NL	0.118	2	[4]
NN3.0NN	0.118	3	[4]

List of PDFs available with MCFM

Test Of MCFM

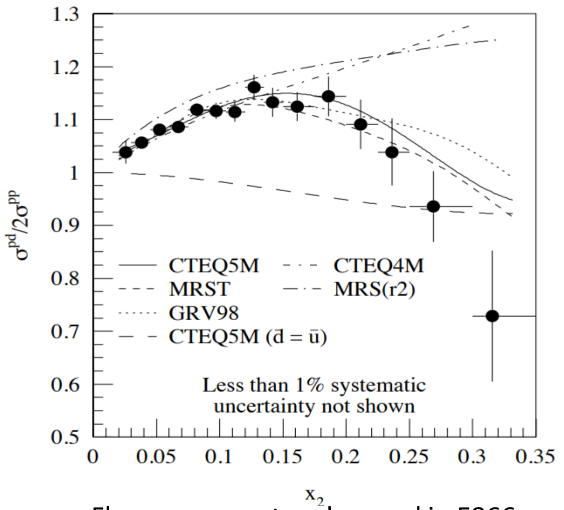
Medium energies (Comparison with experiments E866 and E772) $\sqrt{S}$=38.7 GeV

Effects:

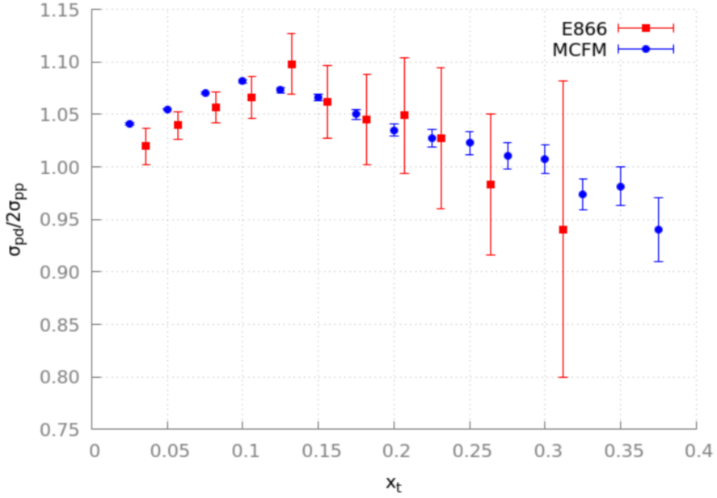
1. **EMC effect:** DIS cross-section from the nucleons in nucleus is different from same number of free nucleons(E772)

2. Flavor Asymmetry (NuSea/E866) experiment at Fermilab to measure to test flavor asymmetry in the nucleon using deuteron.

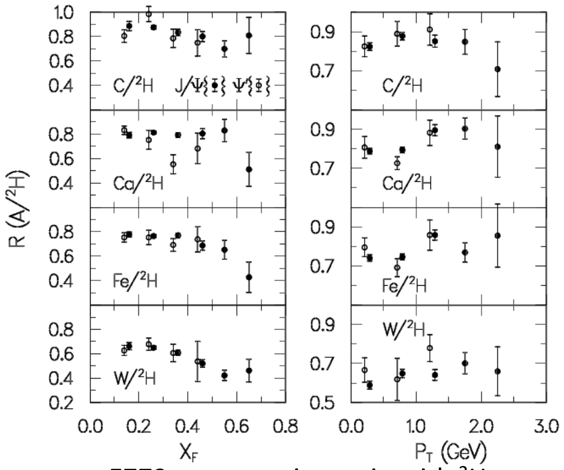
E1039 $\sqrt{s}$ =15GeV



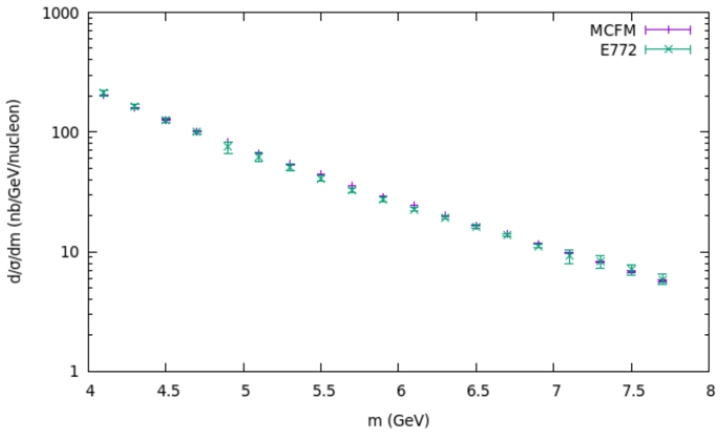
Flavor asymmetry observed in E866



Comparison of E866 with MCFM



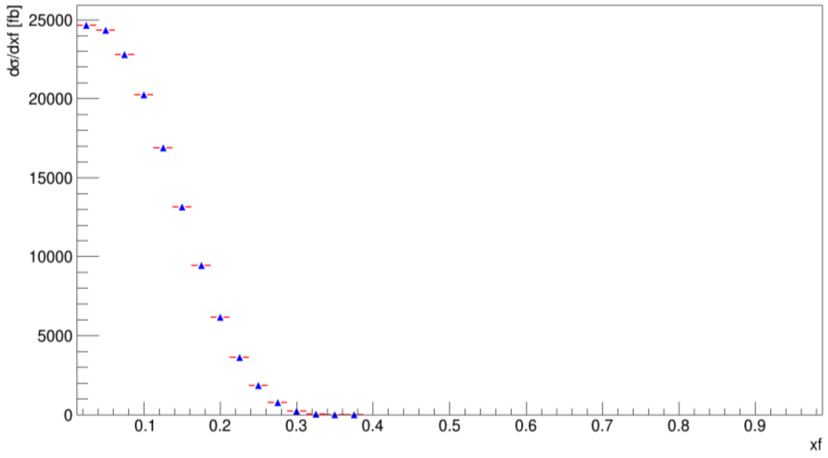
E772 cross-section ratio with ^{2}H



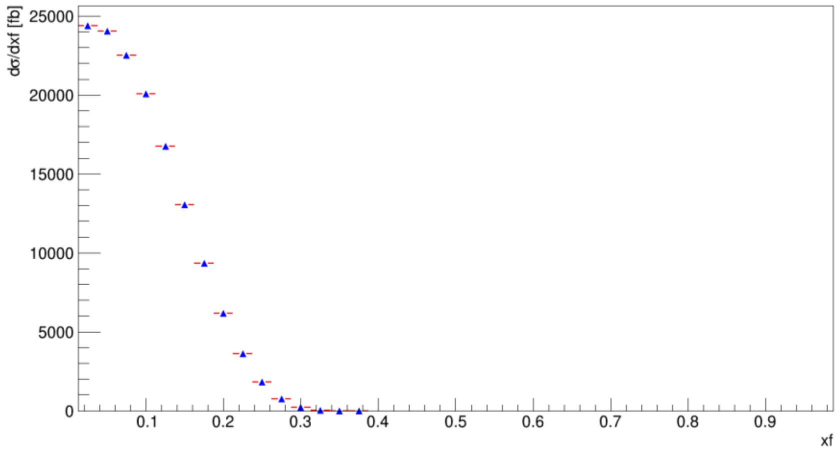
Comparison of E772 with MCFM

MCFM Generated Cross-Sections (E1039)

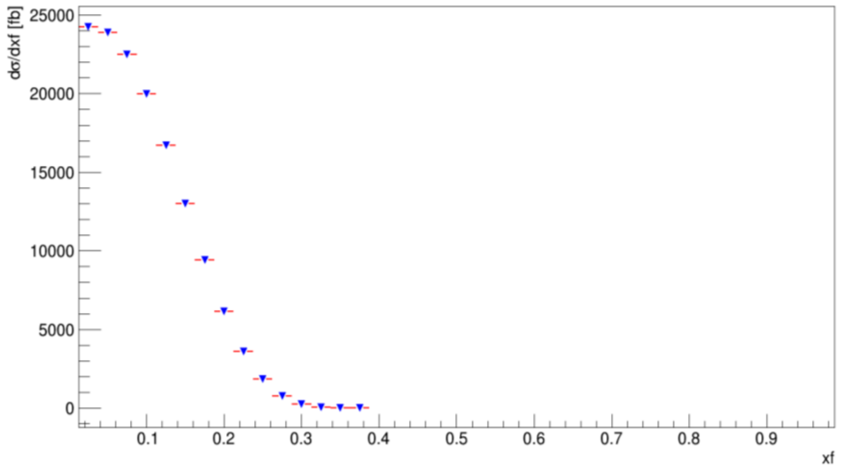
- MCFM generated twenty million events (fifty iterations of four-hundred thousand events each) by sampling the CT14 PDFs.
- Cross-section calculated using MCFM for Nitrogen and Hydrogen at: $\sqrt{s}$ =15GeV
- PDF Label: CT14.NL (next to leading order)
- LHAPDF grid file: MSTW2008 NLO



Helium cross-section(E1039)



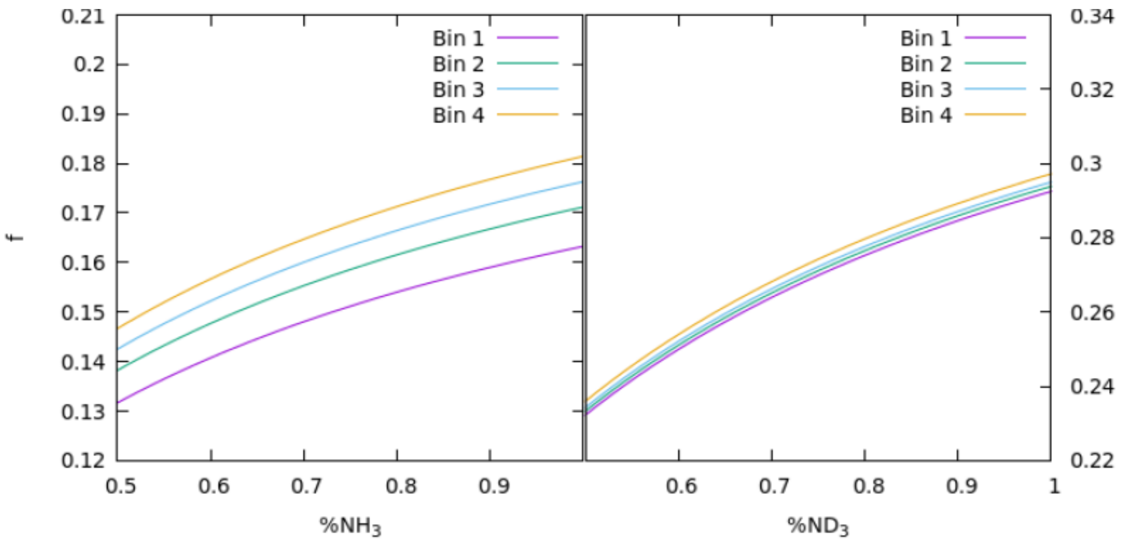
Nitrogen cross-section(E1039)



Aluminum cross-section(E1039)

Target Composition Dependence

- Dilution factor also depends on the materials in the target.
- Using helium differential cross-sections, we found the dilution factor for different ratios of ammonia to helium.
- By doing so, we were able to estimate effect of uncertainty in target composition.
- The cups are made up of polychlorotrifluoroethylene.



Dilution factor for mixtures of ammonia and Helium for different ratios of ammonia. Effect of packing fraction

Bin	X_T
1	0.10-0.16
2	0.16-0.2
3	0.20-0.24
4	0.24-0.60

Bin	$\bar{d}/\bar{u}$ (%)	EMC (%)	NH_3 Error (%)
0.10-0.16	0.5	0.5	0.7
0.16-0.20	1.0	0.5	1.1
0.20-0.24	1.5	0.5	1.6
0.24-0.6	2.0	1.5	2.5

Relative dilution factor calculation can help with reducing the error due to target composition

Summary

- Many systematic error components to the target that need to be managed.
- One of the critical ones is the dilution factor.
- Explained using MCFM to create an event generator to be used in monte-carlo simulations to be used in the study of various target materials.
- Able to estimate the dynamic dilution factor as a function of Drell-Yan kinematics and the corresponding systematic error in each bin.
- Moving forward:

❑ Do a thorough analysis of acceptance of dimuons from various materials.

❑ Looking in detail in other target systematics.